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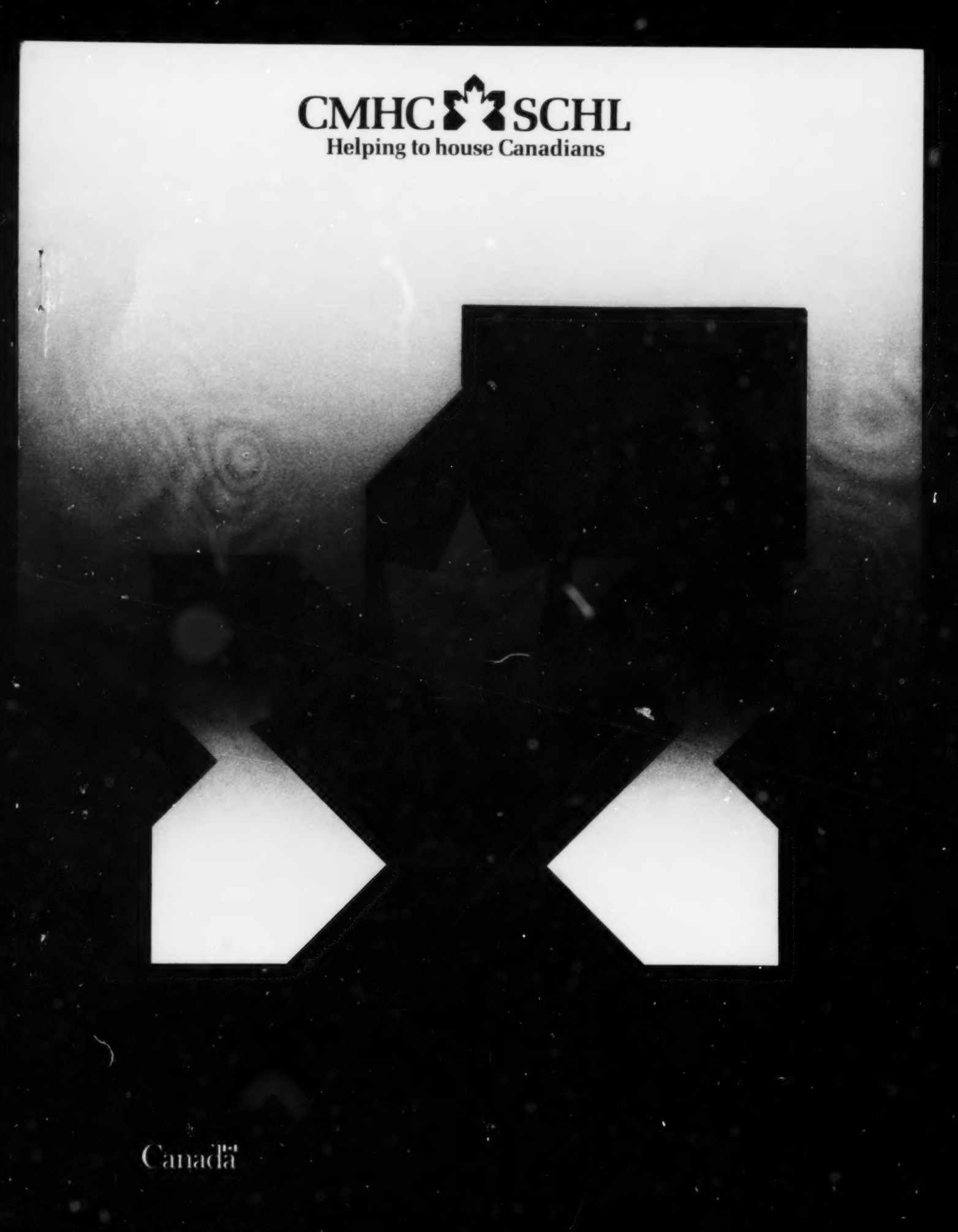

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MEETING CANADIAN RESIDENTIAL VENTILATION STANDARD REQUIREMENTS WITH LOW-COST SYSTEMS

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ABSTRACT

Several low-cost ventilation systems, intended to meet the continuous ventilation requirements specified in the Canadian residential ventilation standard, CSA F326, were investigated. Eight ventilation system configurations were installed, commissioned, and tested in the field to obtain operating experience with the systems and to establish confidence in the simulation software. Carbon dioxide and formaldehyde levels were simulated in houses with several different ventilation system configurations. The cases modeled included houses with and without forced-air recirculation systems, average and tight building envelopes, and average and heavy occupancies. It was determined that several low-cost techniques, including fan-driven limited distribution systems combined with one or more exhaust fans, can be effective in providing good indoor air quality control, while some other techniques should not be relied on. Examination of continuous CO_2 measurements in two mechanically ventilated houses suggested that the fresh air supply rates specified by CSA F326 provide good control of this contaminant.

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Efficacité d'installations de ventilation mécanique économiques

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Plusieurs installations de ventilation économique conçues pour respecter les exigences de ventilation continue de la norme F326 «Residential Mechanical Ventilation Systems» de la CSA ont fait l'objet d'une investigation. Huit systèmes de ventilation ont été installés, mis en service et à l'essai dans le but de documenter leur utilisation et de confirmer leurs caractéristiques de tenue en service en vue de leur simulation informatique. Les teneurs en dioxyde de carbone et en formaldéhyde ont été simulées dans des maisons témoins en variant la configuration des systèmes de ventilation, l'étanchéité à l'air de l'enveloppe et le nombre d'occupants.

On a constaté que des ventilateurs de meilleure qualité pour la salle de bains et la cuisine étaient en mesure de fournir la capacité requise. Relever leur qualité permet d'éviter les problèmes de bruit et de durabilité découlant d'un fonctionnement constant. En l'absence de ventilation directe grâce à la distribution d'air d'alimentation, des taux de renouvellement interne aussi faibles que 0,5 par heure semblent suffisants à cette fin.

Dans les maisons dotées d'installations de chauffage à air chaud pulsé, il est relativement simple de pourvoir le circuit de recirculation d'un conduit de ventilation mécanique, mais cela occasionne des problèmes de condensation dans l'échangeur de chaleur du générateur. Les conduits passifs raccordés au circuit de reprise des installations de chauffage à air chaud pulsé ne sont utiles que pour diminuer la dépressurisation de la maison. La méthode la plus simple de se conformer à la norme CSA F326 dans les maisons chauffées au gaz consiste à utiliser un ventilateur d'extraction et d'induction de tirage. Ce type de ventilateur pourrait fonctionner continuellement au débit requis pour la ventilation et disposerait d'une commande de priorité servant à évacuer sur demande les gaz de combustion provenant du générateur de chaleur ou du chauffe-eau. Il faudrait au préalable obtenir l'approbation des autorités compétentes.

Dans le cas des maisons chauffées par plinthes électriques ou d'autres maisons sans système de recirculation d'air, l'ajout d'une installation restreinte de ventilation et de distribution d'air faisant appel à des conduits de faible diamètre ou à des ventilateurs individuels constitue une option viable. La distribution directe d'air d'alimentation ne semble pas nécessaire pour toutes les pièces lorsqu'elles communiquent

entre elles et que l'une d'elles dispose d'une ventilation adéquate.

Les conduits passifs d'admission d'air raccordés aux systèmes mécaniques assurant uniquement l'évacuation ne permettent pas une bonne circulation de l'air, dans certaines conditions normales de fonctionnement, et ne peuvent donc pas constituer une option fiable pour distribuer l'air de ventilation.

Toutes les simulations informatisées ont démontré des concentrations de contaminants en deçà des limites prescrites par l'ASHRAE et par Santé et Bien-être social Canada. Par ailleurs, les chambres fermées et les systèmes de ventilation mécanique assurant uniquement l'extraction de l'air, sans recirculation d'air extérieur, n'ont pas fait l'objet d'une simulation, puisqu'ils n'auraient pas réussi les essais.

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INTRODUCTION

CSA standard F326 describes requirements for mechanical ventilation systems that are intended to provide adequate indoor air quality control in single-family residences (CSA 1989). A significant number of houses are approaching an airtightness that requires continuous mechanical ventilation. The most common systems designed for continuous ventilation are heat recovery ventilators. While this is an effective and energy-efficient approach, the expense is not yet justified in most houses. This study was initiated to investigate some lower-cost alternatives that also provide adequate indoor air quality control. These less expensive systems are needed in houses with and without forced-air distribution systems and in houses with and without natural draft combustion appliances. Applicability to the lower cost housing market was of particular importance. The primary objective was to determine if simple, inexpensive ventilation systems could meet the intent of CSA F326.

COMMISSION TESTING OF VENTILATION SYSTEMS

An electric-baseboard-heated house, house E, and a forced-air gas-heated house, house G, described in Table 1, were selected for ventilation system installation and commission testing. Both are two-story-plus basement structures, typical of new, urban, single-family home construction in southern Ontario. They were both well suited for allowing installation of the required ventilation system configurations (Table 2) and close to average airtightness for two-story houses, as given by Shaw (1987). The electric-baseboard-heated house was also equipped with a full forced-air distribution system, which simplified installation of the ducted fresh air supply ventilation systems.

Electrically Heated Houses

System E1 Figure 1 displays systems for houses without forced-air distribution systems. System E1 used continuously operating kitchen and bathroom exhaust fans and a small-diameter duct system to supply 5 L/s of fresh air to each category A room (CSA 1989), except the master bedroom and basement to which 10 L/s were supplied. Calculation suggests that the supply of 80 L/s, through a 150-mm-diameter plenum with 52-mm-diameter branches, can easily be provided by a 37 W (1/20 hp) fan operating against a static pressure loss of 90 Pa (0.36 in. H_2O).

An axial (propeller) exhaust fan, with variable-speed control, was installed and sealed in the kitchen window opening of the electric-heated house, as the existing kitchen range hood was of the nonvented recirculation type. An upgraded exhaust fan was also installed in the

second floor bathroom. Supply air was ducted to all habitable rooms except the bathrooms and kitchen.

The fresh air and exhaust fans were turned on and adjusted (except for the single-speed bathroom fan) to achieve flow rates of 74 L/s fresh air, 30 L/s bathroom exhaust, and 45 L/s kitchen exhaust. Airflows were measured at each supply grille, using a pressure-drop-compensating flow hood. The outdoor-to-indoor pressure difference was measured at the sill plate level using an electronic micromanometer.

Although this is not expected to become a normal commissioning test, zonal air change rates were investigated by performing a CO_2 decay test in the living room as follows. The furnace fan was forced to run while compressed CO_2 gas was injected into the cold air return of the furnace. The carbon dioxide concentration was measured in the living room, using an infrared analyzer and a strip chart recorder. Once the concentration steadied at a sufficiently high level (about 4000 ppm), the release of CO_2 was stopped, the furnace fan shut off, and the distribution system under test started up. The house was evacuated of people for approximately one hour so that there were no CO_2 sources in the space during the test. The CO_2 concentration decay recorded on the strip chart was subsequently analyzed to determine the effective ventilation rate for that space:

$$V / v = (C_i - C_f) / (C \times t) \quad (1)$$

$$C = (C_i + C_f) / 2 - C_o \quad (2)$$

where

V = ventilation rate
v = room volume
C_i = initial concentration
C_f = final concentration
C = average concentration
C_o = outdoor concentration
t = time.

System E1 made use of an air distribution system that was already present in the electric-baseboard-heated house instead of a small-diameter system intended specifically for small volumes of fresh air. As a result of leaks in the installed system, it was not possible to supply 5 L/s to three of the bedrooms and 10 L/s to the basement (Table 3). It is believed that much of the leakage was from basement ductwork. The living room CO_2 decay test indicated that the effective hourly air change rate in that room was 0.6, suggesting that contaminant control should be adequate. The main drawback of this system is the amount

of ducting that would be required, particularly in electric-baseboard-heated houses.

System E2 System E2 (Figure 1) was much the same as E1, except supply ducts were only provided to the bedrooms and basement. The commission testing followed the same procedure described for E1. The limitation related to leaking ductwork was as evident in system E2 as it was in E1. While fewer supply points suggest a simpler, lower-cost distribution system installation, they also imply inferior air distribution. However, the living room CO_2 decay test suggests that, at the sensor location on a sofa, the effective air change rate is essentially the same as for System E1. Interzonal convection apparently dominates the air mixing between open rooms. CSA F326 does not require fresh air supply to living and dining areas when they are connected to supplied areas by open archways.

System E3 System E3 used the same exhaust provisions as E1 and E2, but fresh air was provided by eight small, continuously operating supply fans installed in the exterior wall of each category A room. Each of the fans (one in the basement, three on the first floor, four on the second floor) was adjusted to provide a design flow rate of approximately 10 L/s, directed toward the ceiling. The supply and exhaust flows, as well as the outdoor to indoor pressure difference, were measured using the instruments noted above.

System E3 provided excellent fresh air distribution, but the cost of installing a fan and providing power to it in each category A room may be prohibitive in low-cost housing. In this work, hardware plus installation cost approximately $100 per fan. Some potential for savings exists if the fan could be integrated into the baseboard heater. A reduced number of supply points would also benefit this system.

System E4 System E4 was very much like system E3, except that the eight small fresh-air supply fans were replaced with openings through which fresh air was allowed to enter. This system was intended to allow the effectiveness of a passively distributed fresh-air supply system to be evaluated.

Each of the fan-driven fresh-air supply systems (E1, E2, and E3) was able to provide balanced ventilation flows, but System E4 was not. The passive inlets on the main floor each supplied approximately 1.5 L/s of fresh air, while those on the second floor delivered about 0.5 L/s. Testing was done on a typical February day in Toronto (about -4 °C). Since the outdoor-to-indoor pressure difference varies with temperature difference, wind speed and direction, and the volume flow rate of air being exhausted, this type of system would not reliably provide ventilation air, especially to second-story rooms. Shaw (1987) shows an example of such a system with the neutral pressure plane at the ceiling of the second story. While this suggests that a very small pressure difference will exist, to drive some air in through a passive vent, a decrease in the exhaust flow or the indoor-to-outdoor temperature difference could readily stagnate this supply flow.

Gas Heated Houses

System G1 Figure 2 depicts systems for houses having forced-air distribution. System G1 consisted of a passive fresh air duct connected directly to the cold air return plenum of the furnace, with upgraded bathroom and kitchen exhaust fans together providing the total house exhaust requirement. The capability for continuous operation of both the furnace distribution fan and the two exhaust fans was required. In order to achieve the required flow rates and low noise levels necessary for continuous operation, products that are upgraded, relative to standard builder-installed equipment, were used.

A 150-mm-diameter duct was connected to the cold air return plenum of the furnace. The exhaust fans were turned on and adjusted to operate at design flow rates, while the furnace fan was run continuously. Fresh air supply and exhaust fan flow rates were measured, as were airflow rates at each distribution system supply and return grille. The heating system's distribution airflow rate (recirculation) was also measured. An attempt was made to measure outdoor to indoor pressure difference at the sill plate level, but gusty winds prevented good readings from being obtained. Tables 4 and 5 display commissioning results.

This system did not provide balanced ventilation flows. With the fresh-air mixer and wide-open damper in place, the system delivered 40 L/s of fresh air compared to a sum of 76 L/s being exhausted in the kitchen and bathroom. When the damper and mixer were removed, approximately 50 L/s was supplied through the 3-m-long duct. The passive supply duct alone would not satisfy the ventilation rate required. While flow imbalances are not in themselves a problem (since infiltration/exfiltration provide a balance), the resulting depressurization may be unacceptable in some houses. For example, if the above-noted flow imbalance of 36 L/s is added to a 75 L/s dryer exhaust, a 5 Pa depressurization would result in roughly half of new detached Canadian housing (Hamlin et al. 1989).

Measured cold air return temperatures, reported in Table 5, provide an indication of the potential for condensation formation on the furnace heat exchanger. If a heat exchanger of constant effectiveness is used to model the inlet duct, an Ottawa outdoor design temperature of -25 °C would result in a worst-case cold air return temperature of approximately 7 °C. This fails the F326 requirement of 12 °C. Therefore, active exhaust is required to meet the ventilation rate, and fresh air supply ducts connected to the cold air return are of limited use in correcting flow imbalances.

System G2 System G2 was essentially the same as G1 but with a fan added to the fresh air supply duct to ensure the ability to provide balanced ventilation. Although this improves the flow performance, the temperature/condensation problem is aggravated.

The use of the furnace fan to distribute fresh air throughout the house appears to have provided reasonably good distribution. With 15% of the recirculation air being fresh air, each category A room needs to have 33 L/s of recirculation air to receive 5 L/s of ventilation air. While this was not strictly the case, according to Table 4, flow through rooms, from other areas, appears to at least partially make up for any short-falls.

CO_2 decay testing indicates that system G2 provided an effective hourly air change rate of 0.6 in the living room, which is equivalent to an effective ventilation rate of roughly 4.5 L/s for that space. If this space is typical, the commission testing suggests that this ventilation system is likely to provide adequate air quality control.

System G3 System G3 was the same as system G2 except that the furnace fan was not run continuously. Instead, the fresh air supply fan was used to distribute air through the supply and return ducts. Evaluation of this system was intended to determine if continuous furnace fan operation is actually necessary. Much lower total airflows (75 L/s versus 500 L/s) were experienced and generally poorer air distribution than with system G2 was the result, as may be seen in Table 4. The CO_2 decay test indicated that, for the living room, the effective air change rate was only about 10% lower than for system G2. This was likely due to the high proportion of ventilation air being supplied to the adjacent dining room.

System G4 System G4 utilized a fresh air fan and continuously operating furnace distribution fan, as in system G2. A draft inducer was used to vent exhaust products from the furnace and the domestic hot water tank and also exhaust air from the living space. Exhaust fans were also provided in the kitchen and bathrooms to be operated intermittently as required. This system was intended to ensure that design ventilation rates are reliably provided, while ensuring that combustion products from the furnace and hot water tank are safely exhausted. Only a single exhaust air pickup point was used in system G4, as it was installed. (This could, of course, be altered to allow exhaust pickup in the bathroom and kitchen, for example).

The living room CO_2 decay test showed an effective hourly air change rate of 0.56, essentially the same as that for G3 but, in this case, the room-to-room variation in ventilation air supply should be smaller, with less likelihood of problem areas. Since the combustion air requirement was less than the ventilation requirement, the total airflow through the house was reduced by that amount; however, the draft-inducing fan must run continuously. Each of the fan-driven fresh air supply systems (G2, G3, and G4) was able to provide balanced ventilation flows. Because system G4 ensures combustion venting and provides ventilation airflow without the need for depressurization checking, it appears to be the best system for gas-heated houses.

MEASURED CONTAMINANT LEVELS

Field commissioning of the eight systems provided a clear indication of how effectively contaminant levels were being controlled by the various ventilation rates and systems in only some areas of the houses. The understanding of room-to-room variations in ventilation effectiveness may be improved through simulations and examination of measured contaminant concentrations in mechanically ventilated houses.

Several months of hourly-average CO_2 concentration data for houses A and B, described in Table 1, were examined. Each house employed an HRV, which exhausted air from the bathrooms and kitchen. In house A, fresh air was distributed through the heating system ductwork with a continuously operating furnace fan. In house B, a single-point fresh air

supply in the utility/mechanical room was used without any mechanical air recirculation.

Data recorded in the family room, kitchen, dining room, and master bedroom of house A revealed that the CO_2 concentration never exceeded 1000 ppm, but it exceeded 800 ppm in each of the monitored rooms in the evening on a few occasions. This pattern would be expected if guests were in the house with the two regular occupants. The fresh air supply for the whole period averaged 39 L/s (20 L/s per occupant) or 0.2 air changes per hour, while the average indoor CO_2 level was about 380 ppm with an outdoor concentration of approximately 330 ppm. This ventilation rate was more than adequate to provide good CO_2 level control[1] in this lightly occupied house. Subsequent formaldehyde concentration measurements indicated that the ventilation was also more than adequate to keep this contaminant concentration under the Health and Welfare Canada (NHW 1987) target level of 0.05 ppm.

In house B, indoor CO_2 levels were measured in the family room and master bedroom, and the fresh air supply flow rate was varied above and below the norm of about 40 L/s or 0.3 ach. Figure 3 shows the ventilation rates and resulting average CO_2 concentrations measured for seven different time periods. It shows a clear relationship that suggests average CO_2 levels may be kept below 600 ppm in this house with ventilation rates of roughly 40 L/s or 0.3 ach. Closer examination of the data show, however, that in November when this ventilation rate was used, family room CO_2 concentrations peaked at over 1000 ppm on several occasions, while bedroom levels were typically under 650 ppm. This house is occupied by two adults, two children, a dog, and a cat.

Formaldehyde levels were measured in four rooms of this house for three different periods. The maximum concentration observed was 0.053 ppm (well below the 0.1 ppm action level but just above the 0.05 target level) for a period when the HRV was not operating. This suggests that if the CO_2 concentration is controlled to be within a comfortable range, the formaldehyde concentration will likely be well under the target-level long-term objective.

It is expected that family room pollutant concentrations could have been reduced through the use of either a supply or an exhaust connection to that room. However, it appears that a ventilation rate of about 10 L/s per occupant provides reasonably good air quality control in this open plan house, even though the system uses only one fresh air supply point and has no mechanical recirculation. The multi-point exhaust system appears to induce flow-through ventilation in most areas of the house.

While much practical information may be obtained through observation and measurement in real systems such as these, simulations are more efficient in determining the effect of individual variables and in making system-to-system comparisons.

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[1] The acceptable long-term exposure range (ALTER) set by Health and Welfare Canada for carbon dioxide is $\leq$ 3500 ppm (NHW 1987). ASHRAE Standard 62-89 (ASHRAE 1989) sets a guideline of 1000 ppm, taking CO_2 concentration as an indicator of the level of occupancy related contaminants.

SIMULATION OF CONTAMINANT LEVELS

Simulations were used to evaluate several different ventilation system configurations, with various occupancies and building leakage characteristics, to extend the results obtained in the field and broaden their applicability.

Program Calibration

The software used (EE 1990; Axley 1988) is a combination of the National Bureau of Standards (now National Institute of Standards and Technology) contaminant concentration simulation program and a building energy analysis program to handle airflows (by ensuring conservation of mass). To calibrate the model, simulated CO_2 levels were compared to measured data, for house B, over a one-month period. Good agreement was obtained.

Air change rates determined from simulated CO_2 decay rates in the living rooms of the gas-heated and electrically heated houses (operating with various ventilation systems) were compared to measured rates. Agreement was again found to be generally good.

System Simulations

Following the program calibration exercise, ten different house/system configurations were simulated. Included were systems with and without recirculation, various supply systems, and buildings that were of average and tight construction, having average and heavy occupancy. Simulations using average tightness and occupancy should typify system performance in new construction, while tight construction in combination with heavy occupancy should represent an extreme design condition. Six systems that used recirculation (designated R1 to R6) were modeled as having four zones: basement, living room, other first floor rooms, and bedrooms. Four more systems, which did not have forced recirculation (designated NR1 to NR4), were simulated with the same four zones plus a fifth "second-floor bathroom" zone to account for an exhaust fan installed there.

Interzonal mixing was assumed to be driven by airflows induced by the ventilation system and by natural convection, resulting from small temperature differences between zones. The forced-convection components were based on measured flow rates in houses G and E (Tables 3 and 4), where the commission testing was performed. Natural convection airflows were estimated to be 100 L/s, in each direction, through openings between rooms. For a standard 1.6 m^2 doorway, this corresponds to a mid-room-height temperature difference of approximately 2 °C (Barakat 1985) and is equivalent to an air velocity of 0.1 m/s (a velocity that is frequently encountered inside houses).

Both carbon dioxide and formaldehyde concentrations were simulated. CO_2 was assumed to be typical of occupant-generated contaminants, while HCHO was assumed to be typical of those that are building-generated. The CO_2 generation schedules, which are based on ASHRAE data (ASHRAE 1989), correspond to average and heavy occupancies and appear

in Figure 4. Formaldehyde generation was taken as constant at 2.42 x 10^6 L/s, with 40% of this assumed to be on each of the two above-grade levels and 20% in the basement. This generation rate falls within the mid-range of source strengths found in new, detached Canadian houses (Hamlin et al. 1989). Tight construction employed an nLA of 0.85 cm^2/m^2 while the average tightness assumed 1.61 cm^2/m^2. A 17-day period of Ottawa weather data (days 71 to 87, Figure 5), which included outdoor ambient temperatures between -20 and 15 °C, was selected as input.

Simulation Results

Simulated formaldehyde concentrations were generally found to be very stable with time and, as such, the average level over the simulation period has been plotted for each house zone in Figure 6. In all cases, predicted concentrations of HCHO are well below the target level of 0.05 ppm set by Health and Welfare Canada (NHW 1987). Carbon dioxide concentrations vary markedly with time of day and are, therefore, plotted hour by hour for a typical cold day, for each house zone, in Figures 7 and 8. In each case, predicted CO_2 levels are within the 1000-ppm guideline set in ASHRAE 62-89 (ASHRAE 1989). Weather conditions appeared to have little effect on the simulated concentrations, particularly for the tight construction cases.

Systems Without Recirculation

System NR1 This system, which has a full supply system, is essentially equivalent to the real system E1. Simulated as a house with average tightness and average occupancy, the HCHO levels were well controlled, as may be seen in Figure 6. As a leaky duct system biased the supply of ventilation air to the basement of the house, and the generation rate is taken to be lower there, the formaldehyde level was a minimum in the basement, increasing as the air moved up through the house to the kitchen and second-floor bathroom exhaust fans. Carbon dioxide levels, plotted in Figure 7a, are driven primarily by the strength and location of the contaminant source and changes to these parameters throughout the day. Since there is no CO_2 generation in the basement, the concentrations there stayed at the background level.

System NR2 This house/system is essentially the same as System NR1, except that it was simulated as having a tight envelope and heavy occupancy. The reduced leakage caused formaldehyde concentrations to increase slightly, but the zonal pattern was unchanged. Heavy occupancy clearly raises the average and peak CO_2 concentrations, plotted in Figure 7a, but both contaminants are well controlled.

System NR3 System NR3 is equivalent to System NR2, except that ventilation air is ducted only to the bedrooms and basement, which results in a small decrease in basement HCHO levels and a small increase in first floor levels (Figure 7b). Living room CO_2 levels increase slightly, but the concentration in the first-floor zone with an exhaust fan is essentially unchanged. The peak level is still less than 80% of the ASHRAE guideline. The very limited increase in living room CO_2 concentration is the result of substantial interzonal

mixing, which is taken to be 100 L/s based on laboratory measurements (Barakat 1985).

System NR4 System NR4 is equivalent to system NR3 with all ventilation air being supplied to the basement prior to distribution but without any ventilation air supply to the bedroom. The only air movement through the bedroom zone is the 30 L/s that is drawn through, from the first floor, by the second-floor bathroom. Bedroom CO_2 concentrations also increase, but these remain under 65% of the 1000 ppm recommended level (Figure 7b).

This case is intended to represent the case of a stagnant second-floor bedroom, as may be encountered with passive air supplies when the combination stack effect and exhaust-only ventilation moves the neutral pressure plane to the level of the inlets. While this did not occur during the commission testing, it was observed that second-floor bedroom inlets supplied about one-third of the flow that first-floor inlets did. Shaw's example (c) shows that, for combinations of outdoor temperatures of -8 °C or colder and exhaust flows of 53 L/s or less, the neutral pressure plane will be below the second floor ceiling (Shaw 1987). This causes ventilation air to enter predominantly through openings in the lower parts of the wall.

If a bedroom with a closed door had been modeled, contaminant levels would rise towards a saturation value. For HCHO, this would very likely be above the Health and Welfare guideline. Similarly, CO_2 concentration would be expected to exceed the ASHRAE guideline. Carbon dioxide level measurements in non-mechanically ventilated upper-floor bedrooms found levels up to 2000 ppm .

Systems With Recirculation

System R1 This system, which was simulated with a recirculation rate of 2 ach, is essentially the same as the real system G2. Simulated as a house with average tightness and average occupancy, the formaldehyde levels are well controlled and almost uniform through the four zones, as may be seen in Figure 6. The carbon dioxide levels plotted in Figure 8a also display little variation between the zones, and these concentrations are very well controlled. The recirculation system tends to make use of zones with low concentration levels as sinks, thus tending to limit the peak levels encountered. This case appears to support the treatment of houses with high recirculation rates as single-zone spaces.

System R2 System R2 is essentially the same as System R1, except that it has a tight envelope and heavy occupancy. All HCHO concentrations increase only slightly, suggesting that the total ventilation is dominated by the mechanical system. CO_2 levels increase somewhat as a result of the heavy occupancy (Figure 8a). Both contaminants are still very well controlled, with some margin available for higher occupancy.

System R3 System R3 is identical to R2, except that a recirculation rate of only 0.5 ach is used. This change had no significant effect on the formaldehyde concentrations, but the difference in CO_2 levels between zones more than doubled (Figure 8b). The contaminant concentrations are still well controlled, suggesting that houses with energy-efficient

envelopes can use heating systems with lower recirculation rates (or a two-speed fan) without a significant negative impact on the ventilation system.

System R4 System R4 is the same as System R3, except that it uses a recirculation rate of 1 ach. Again, formaldehyde concentrations are unchanged, and carbon dioxide levels fall between the values for the two previous cases (Figure 8b). This case serves as a basis for comparison with Systems R5 and R6.

System R5 System R5 utilizes a continuously running draft inducer rather than the continuous kitchen and bathroom exhausts used in System R4. The basement HCHO level increases slightly as a result, as do all of the CO_2 concentrations (Figure 8c). Both contaminants remain well controlled, with the peak CO_2 level being at approximately 70% of the 1000 ppm recommended guideline.

System R6 System R6 is similar to System R4, but it did not have a direct connection between the ventilation air supply and the recirculation system, causing the basement to act as a mixing box. Relative to System R4, the basement formaldehyde level dropped substantially, but the others were unchanged. Carbon dioxide concentrations, plotted in Figure 8c, show markedly reduced basement levels and modest changes to the levels in the other zones. As there was no CO_2 source in the basement, this case cannot be taken as representative of the general mixing/supplying zone case.

CONCLUSIONS

Several low-cost ventilation systems have been found to meet CSA F326. Through both commissioning in the field and through computer simulation, they were found to be effective in providing good air quality control.

Generally, upgraded bathroom exhaust fans and kitchen range hoods are an effective way of providing the required exhaust capacity. Upgrading is required to avoid problems of noise and durability.

For electrically heated houses or other houses without a furnace flue or a fresh air distribution system, the addition of a limited distribution system, employing small-diameter ducts or small fan units, appears to be a viable option. Direct supply distribution does not appear to be necessary for rooms that are open to one another when one of them is exhausted. Second-floor passive inlets may stagnate under some normal operating conditions and, therefore, do not constitute a reliable ventilation system option.

In houses with forced-air distribution systems, the addition of a central fan-powered fresh-air supply system is a relatively simple undertaking. Passive ducts connected to the return side of furnaces are only useful in reducing house depressurization. Recirculation rates as low as 0.5 ach appear to be adequate when there is no direct supply air distribution.

The use of a combined function exhaust-air-fan/draft-inducer appears to be a promising option for houses with one or more natural-draft heating appliances. Appropriate

regulatory approvals must still be obtained before this approach may be used out of the lab.

All of the simulated systems controled contaminant concentration levels to within ASHRAE and Health and Welfare Canada guidelines. Systems that would fail to pass, but could not be accurately simulated, include closed, nonventilated spaces in houses with mechanical exhaust-only systems.

REFERENCES

ASHRAE. 1989. ASHRAE Standard 62-1989, Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating, Refrigerating & Air Conditioning Engineers, Inc.

Axley, J. 1988. Progress toward a general analytical method for predicting indoor air pollution in buildings, IAQ modelling Phase III Report. National Bureau of Standards, NBSIR 88-3814.

Barakat, S. A. 1985. "Inter-zone convective heat transfer in buildings; A review". Heat Transfer in Buildings and Structures, HTD Vol. 41, ASME, New York, August.

CSA. 1989. CSA Preliminary Standard F326.1-M1989, Residential mechanical ventilation requirements. Canadian Standards Association, Rexdale, January.

EE. 1990. ENERPASS Version 3.0. Enermodal Engineering Limited, Waterloo, Ontario.

Hamlin, T., M. Lubun, and J. C. Forman. 1989. Ventilation and airtightness in new, detached Canadian housing. CMHC, Ottawa, January.

NHW. 1987. Exposure guidelines for residential indoor air quality. Department of National Health and Welfare, Ottawa, April.

Shaw, C. Y. 1987. Mechanical ventilation and air pressure in houses. I.R.C., N.R.C., Canadian Building Digest 245, Ottawa, May.

Table 1 House Descriptions

House	Type	Floor Area (m2)	Volume (m3)	Heating System	Ventilation System	Air Tightness	
						Cr (L/s.Pa)	n
A	Two levels plus Basement	206	748	Electric / Heat Pump Forced-Air	HRV-plenum supply 4 exhaust points	13.8	0.785
B	Two levels incl. Basement	175	483	Hot Water Radiant Floor	HRV-single supply 5 exhaust points	4.1	0.919
G	Two levels plus Basement	206	750	Gas (Std. Efficiency) Forced-Air	see Table 2	31.0	0.808
E	Two levels plus Basement	216	796	Electric Baseboard	see Table 2	49.6	0.761

Table 2 Ventilation System Summary

House	System Identifier	Supply	Exhaust
Electric	E1	Central Supply Fan (75 L/s) Ducts to each Category A Room	Kitchen Window Fan (45 L/s) Bathroom Exhaust Fan (30 L/s)
	E2	Central Supply Fan (75 L/s) Ducts to Bedrooms and Basement	Kitchen Window Fan (45 L/s) Bathroom Exhaust Fan (30 L/s)
	E3	8 Window-Mounted Supply Fans @ 10 L/s	Kitchen Window Fan (45 L/s) Bathroom Exhaust Fan (30 L/s)
	E4	8 Window-Mounted Passive Inlets	Kitchen Window Fan (45 L/s) Bathroom Exhaust Fan (30 L/s)
Gas	G1	Duct to Cold Air Return Continuous Furnace Recirculation	Kitchen Rangehood (53 L/s) Bathroom Exhaust Fan (22 L/s)
	G2	Central Supply Fan (75 L/s) Continuous Furnace Recirculation	Kitchen Rangehood (53 L/s) Bathroom Exhaust Fan (22 L/s)
	G3	Central Supply Fan (75 L/s) No Recirculation	Kitchen Rangehood (53 L/s) Bathroom Exhaust Fan (22 L/s)
	G4	Central Supply Fan (75 L/s) Continuous Furnace Recirculation	Continuously Operating Draft Inducer (75 L/s)

Table 3 Measured Operating Conditions : Electrically Heated House

	Ventilation Systems			
	E1	E2	E3	E4
Exhaust Flow Rates (L/s)				
Kitchen	49	45	45	42
Bathroom	30	30	30	30
Sum	*79*	*75*	*75*	*72*
Supply Flow Rates (L/s)				
Master bedroom	10	10	10	0.5
Bedroom 2	3.5	3	10	0.5
Bedroom 3	2	2	10	0.5
Bedroom 4	0.5	1	10	0.5
Living Room	5	-	10	1.5
Dining Room	5	-	10	1.5
Family Room	5	-	10	1.5
Laundry Room	5	-	-	-
Bathroom	6	-	-	-
Basement	3.5	3.5	10	1.5
Sum	*45.5*	*19.5*	*80*	*8*
System Flowrate	*74*	*73*	-	-
Outdoor - Indoor ΔP (Pa)	2.0	2.0	3.0	5.5
Living Room Air Change (AC/h)	0.6	0.6	-	-

Table 4 Air Distribution System Flowrates (L/s) : Gas Heated House

Grille Location	Recirculation Fan On		Recirculation Fan Off	
	Supply	Return	Supply	Return *
Master bedroom	11.5	28	1	1
Master Bedroom Closet	39	-	1	-
Ensuite	28	-	1	-
Bedroom 2	30	-	2	-
Bedroom 3	24	12	1	1
Bedroom 4	32	-	1	-
Bathroom	21	-	3	-
Upstairs Hall	32	27	2	4
Living Room	25	-	2	-
Dining Room	8	86	1	14
Kitchen	31	-	5	-
Family Room	26	14.5	3	4
Laundry Room	22	-	2	-
Front Hall	13.5	-	1.5	-
Study	12	-	1	-
Sum	*355*	*168*	*27.5*	*24*
System Flowrate	*500*	-	*78*	-

* return acted as a supply when the recirculation fan was off

Table 5 Measured Operating Conditions : Gas Heated House

Ventilation Systems G1 to G4		
Central Supply System	78 L/s	
Kitchen Rangehood	54 L/s	*(except G4)*
Bathroom Exhaust Fan	22 L/s	*(except G4)*
B-Vent without Draft Inducer	20 L/s	*(except G4)*
Heating System Recirculation	500 L/s	*(except G3)*
Outdoor - Indoor ΔP (sill)	3.5 Pa	*(fan supply : G2 - G4)*
	0 +/- 2.5 Pa	*(passive supply : G1)*
Fresh Air Supply Systems G1 to G4		
Temperatures		
Outdoor Air	-8.3 C	
Cold Air Return minimum	10.6 C	*(no recirculation : G3)*
Cold Air Return minimum	13.3 C	*(recirc. operating : G1,G2,G4)*
Cold Air return maximum	15.6 C	
Draft Inducer System G4		
Flow Rates		
Total Exhaust Flow	74 L/s	
Furnace Branch	29 L/s	
DHW Branch	8 L/s	
Exhaust Air	35 L/s	
Temperatures (both furnace and DHW burner operating)		
Furnace Exhaust	135 C	
Draft Inducer Exhaust	56 C	
Basement Air	16 C	
Living Room Air Change Rate		
System G2	**0.60 AC/h**	
System G3	**0.55 AC/h**	
System G4	**0.56 AC/h**	

List of Figure Captions

Figure 1 Electrically Heated House Systems

Figure 2 Gas Heated House Systems

Figure 3 CO_2 versus Air Change Rate

Figure 4 CO_2 Production Rate Schedules

Figure 5 Outdoor Ambient Temperature : Simulated Period

Figure 6 Average Formaldehyde Concentrations

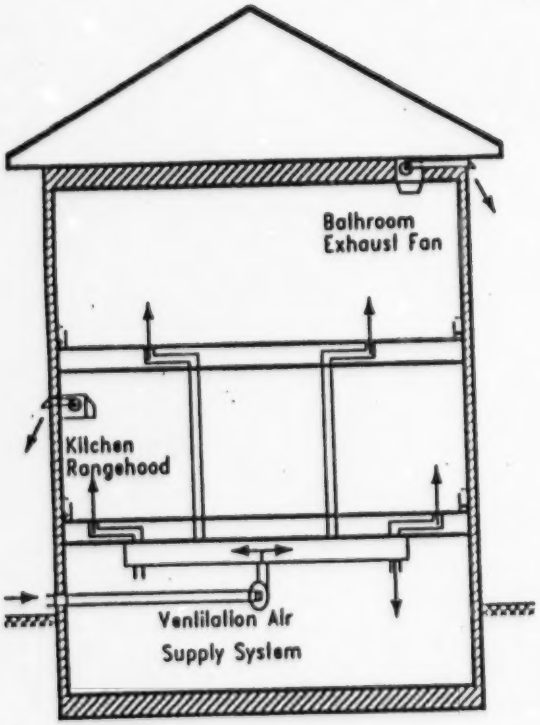
Figure 7a Typical Simulated CO_2 Concentrations : House without Recirculation

Figure 7b Typical Simulated CO_2 Concentrations : House without Recirculation

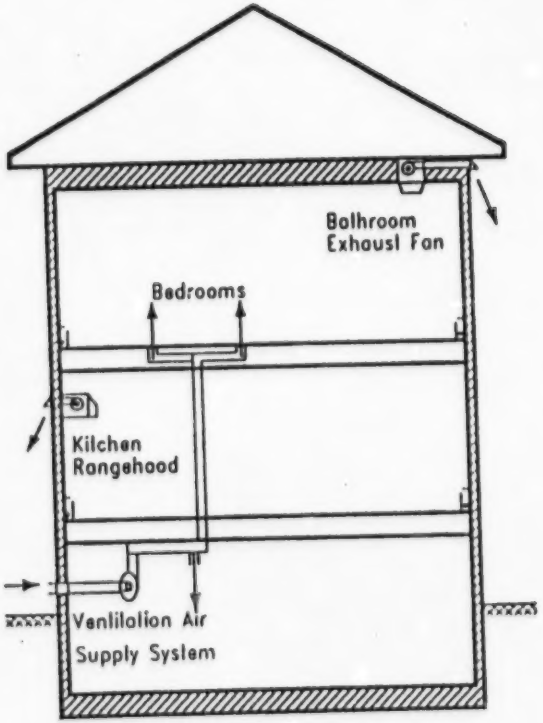
Figure 8a Typical Simulated CO_2 Concentrations : House with Recirculation

Figure 8b Typical Simulated CO_2 Concentrations : House with Recirculation

Figure 8c Typical Simulated CO_2 Concentrations : House with Recirculation



Ventilation System E1



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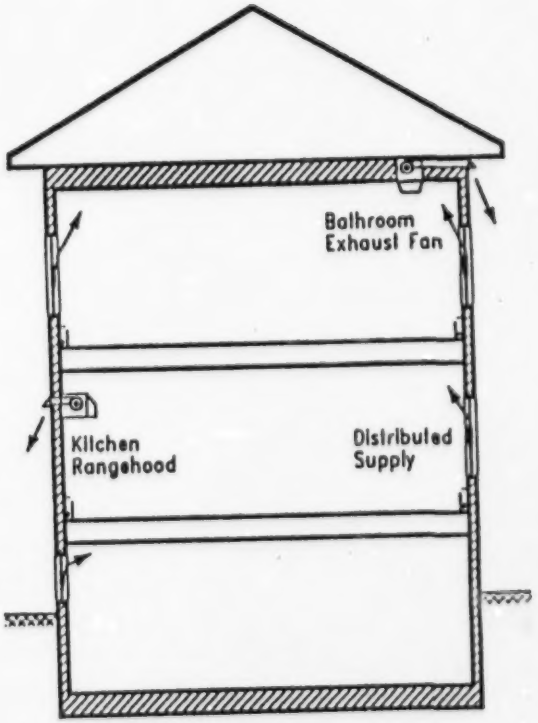
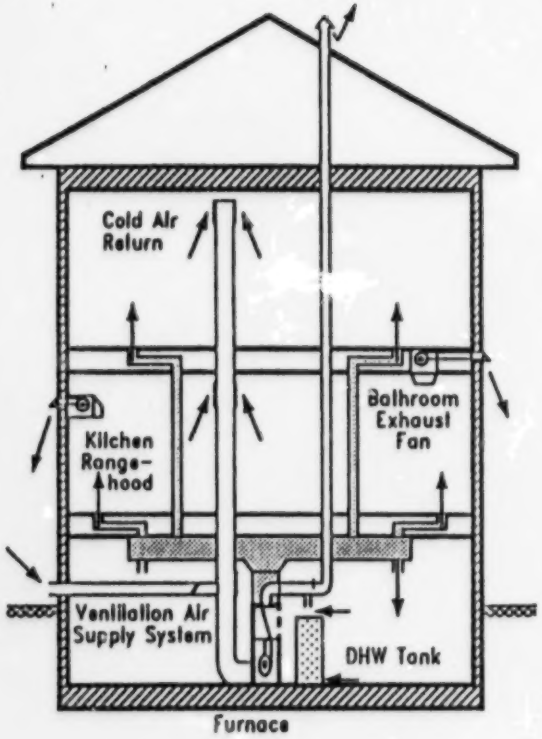
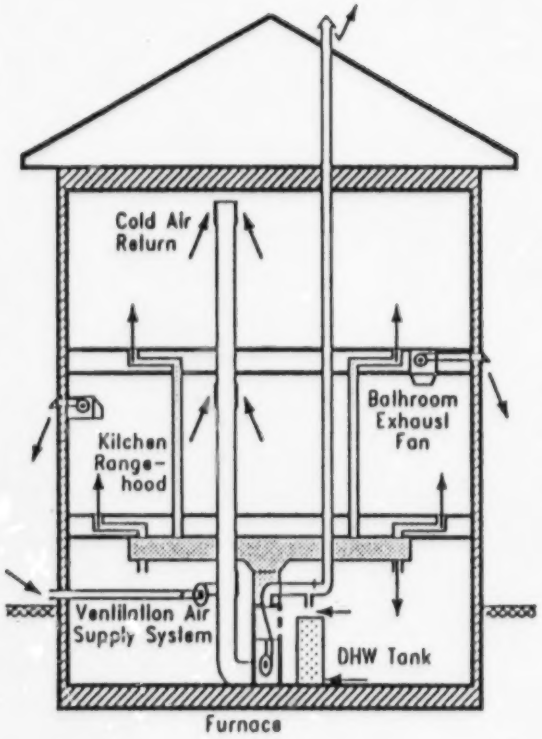


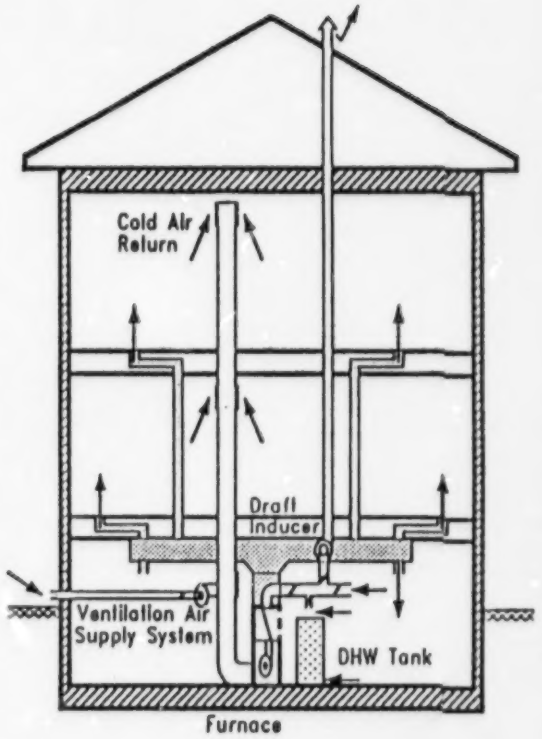
Ventilation System E3 & E4



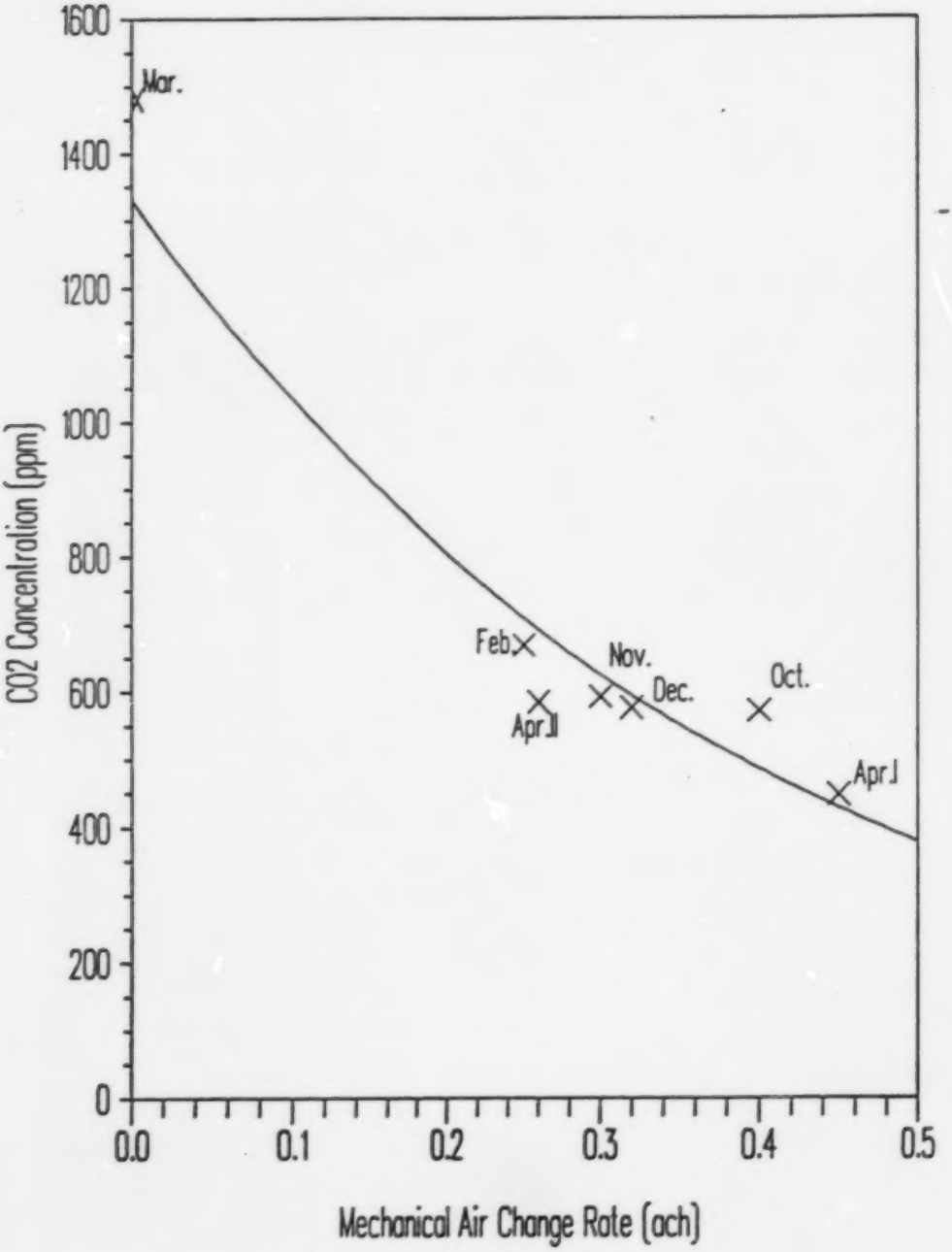
Ventilation System G1

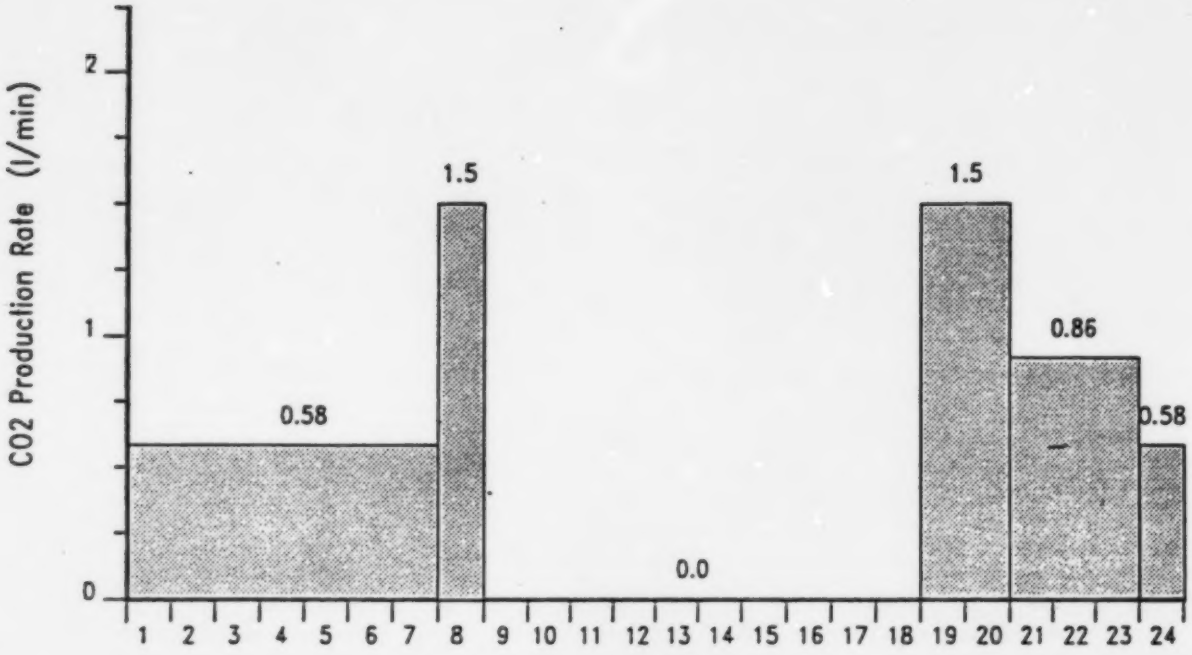


Ventilation Systems G2 & G3

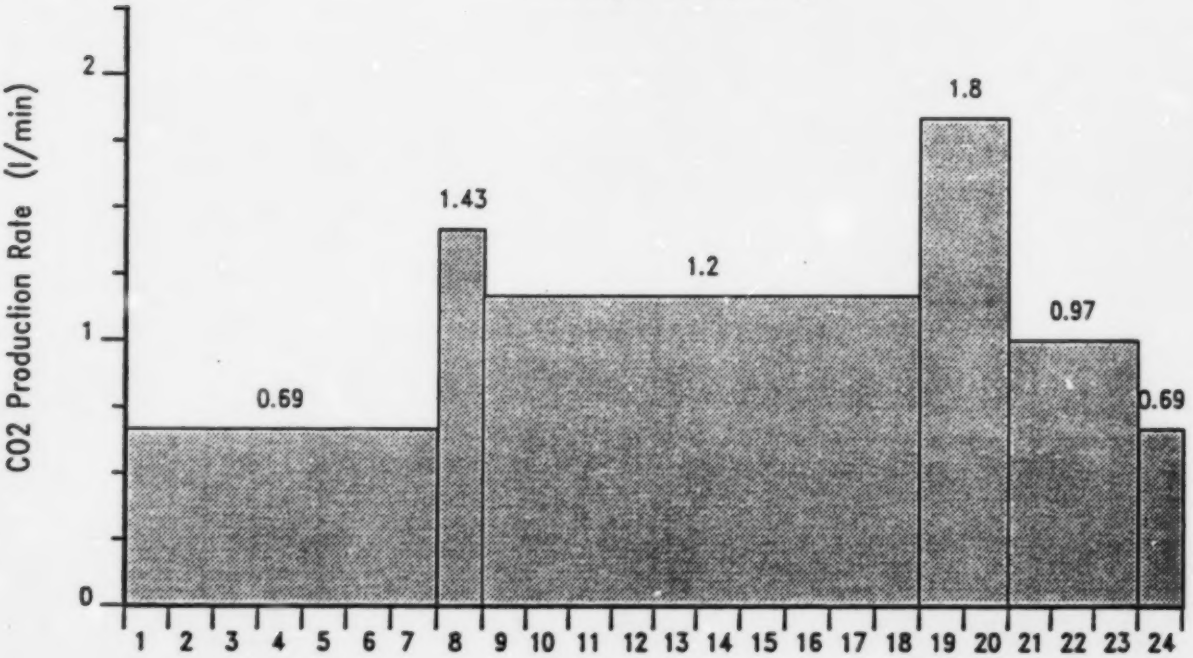


Ventilation System G4

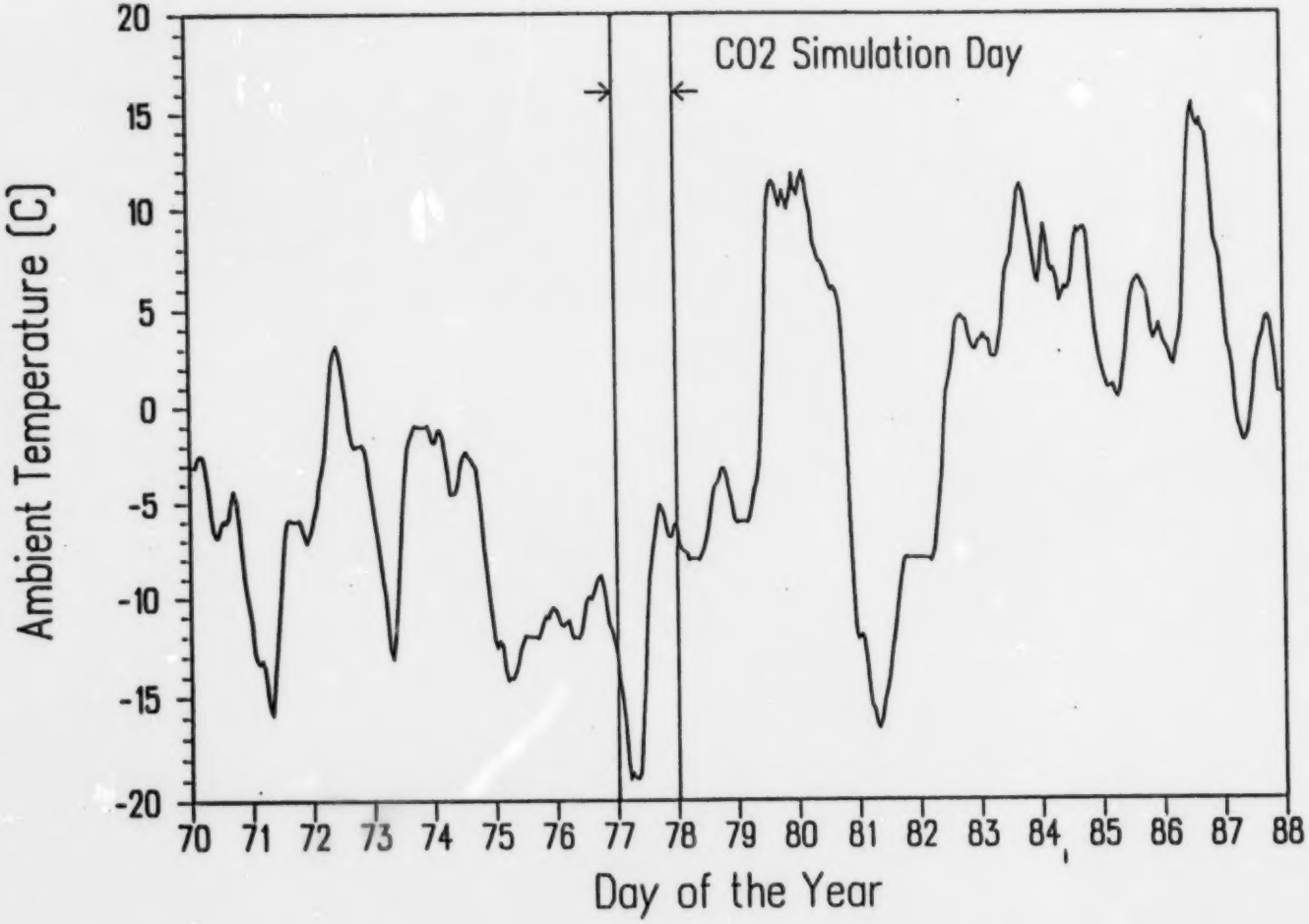

1600
1400
1200
1000
800
600
400
200
0
CO2 Concentration (ppm)
Mar.
Feb.
Apr.II
Nov.
Dec.
Oct.
Apr.I
0.0
0.1
0.2
0.3
0.4
0.5
Mechanical Air Change Rate (ach)



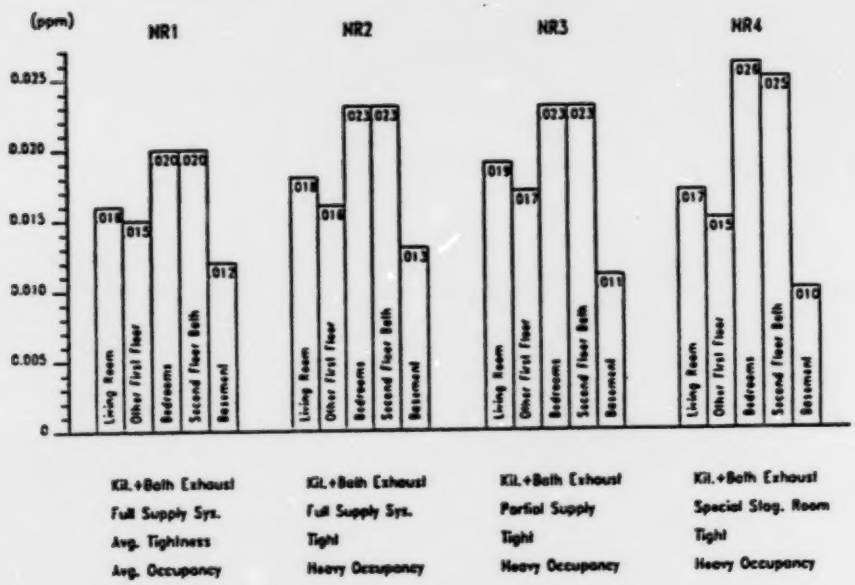
Average Occupancy



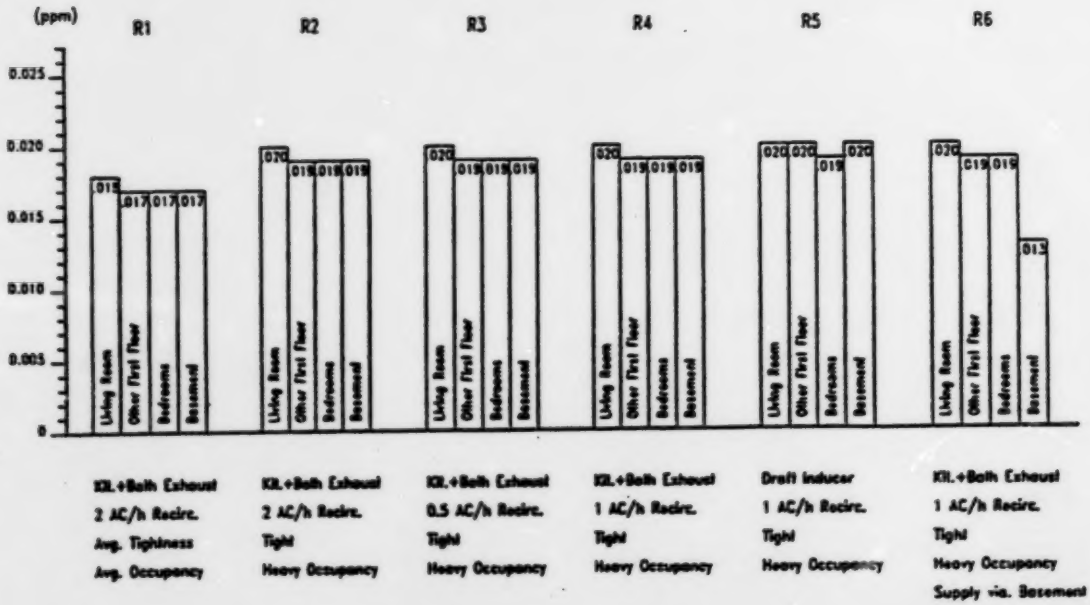
Heavy Occupancy


CO2 Simulation Day
Ambient Temperature (C)
20
15
10
5
0
-5
-10
-15
-20
70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
Day of the Year

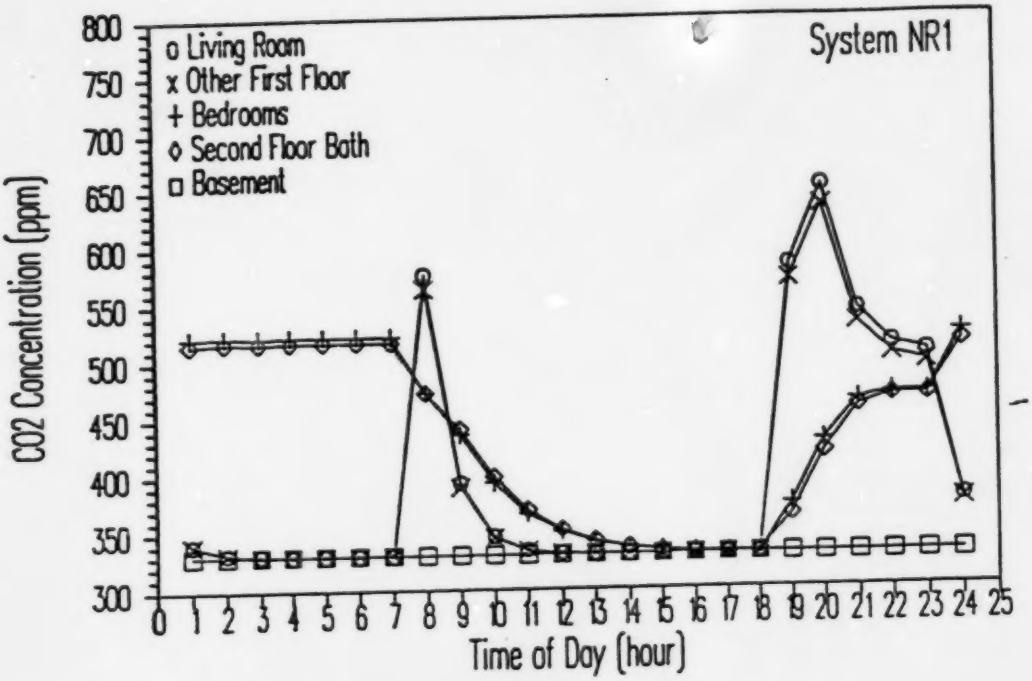
House without Recirculation System

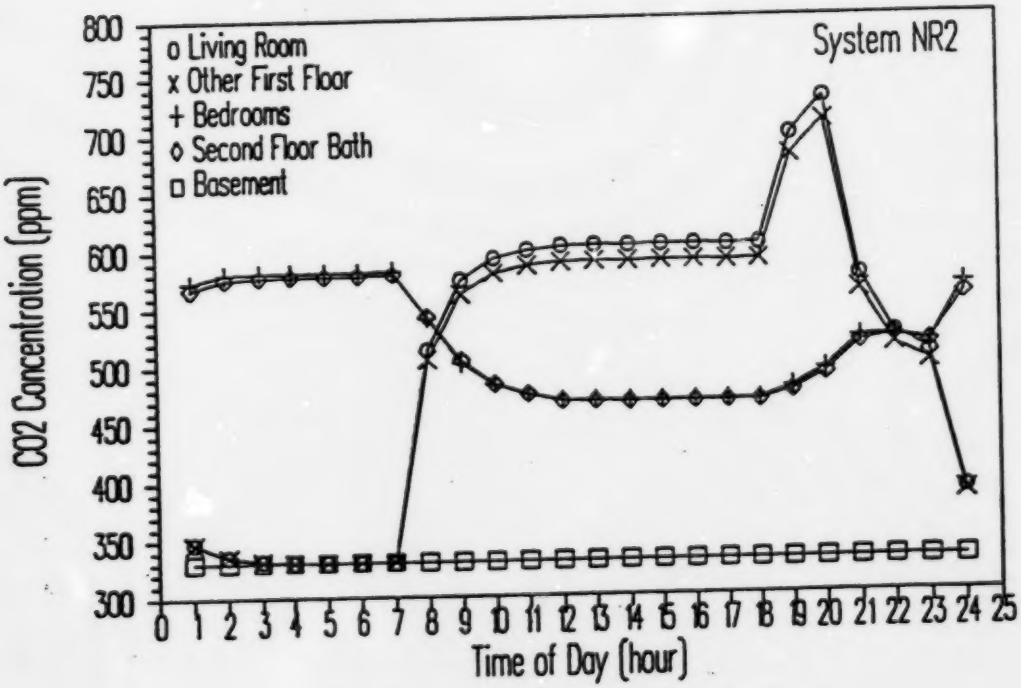


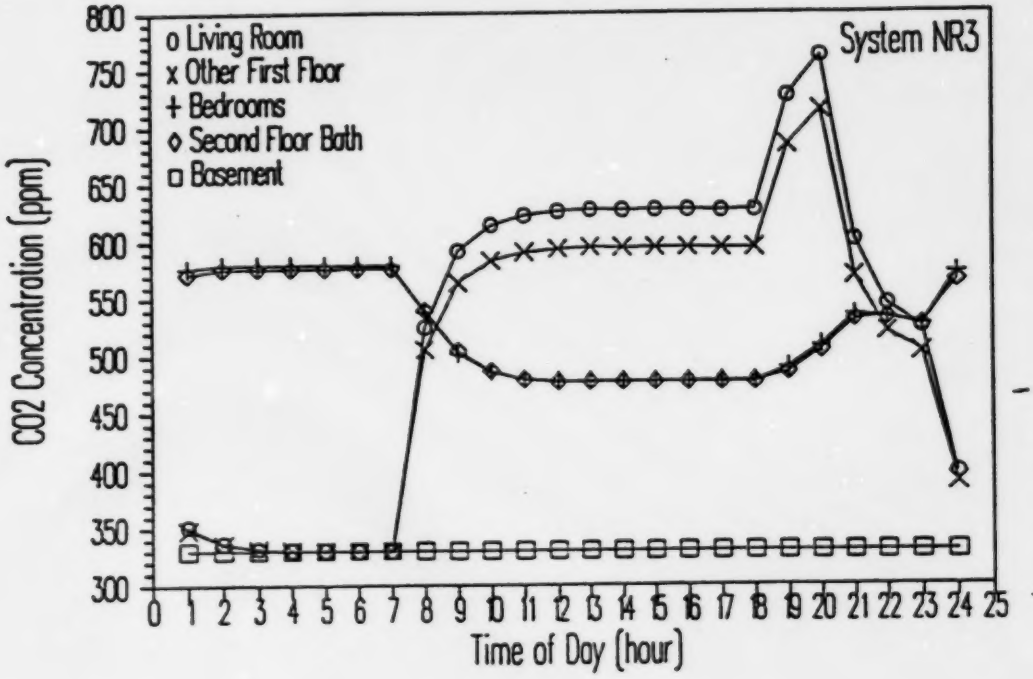
House with Recirculation System

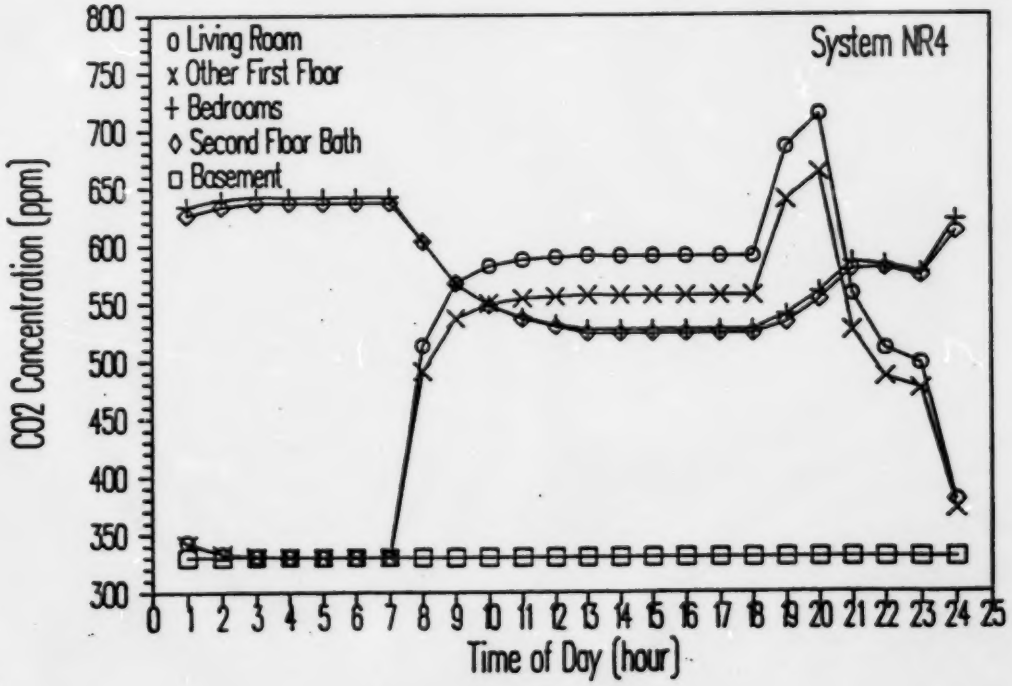


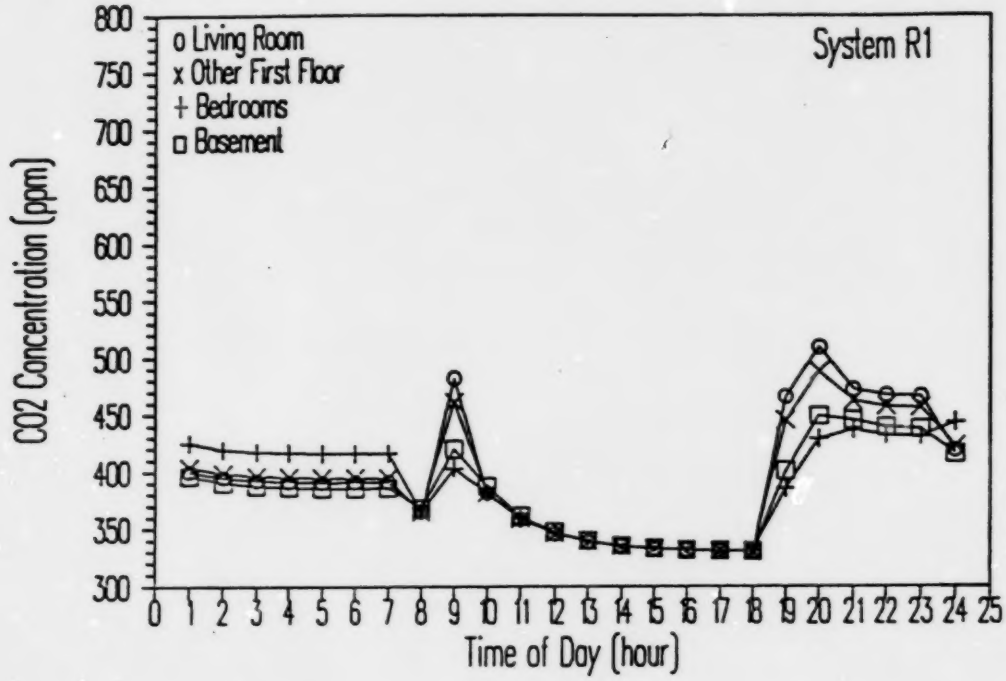
F. -

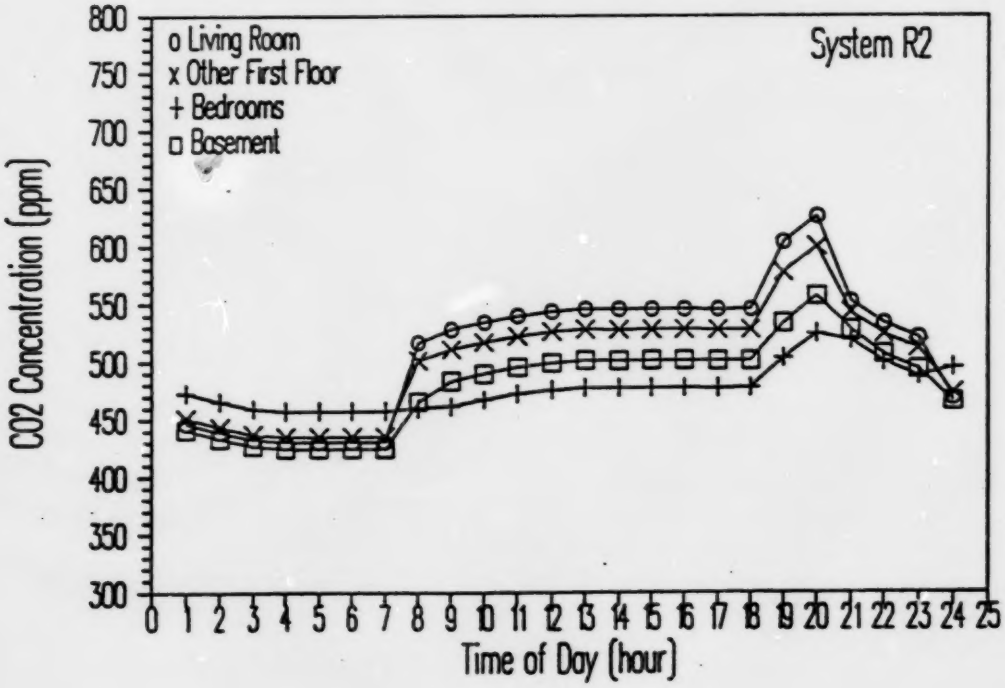

System NR1
o Living Room
x Other First Floor
+ Bedrooms
◊ Second Floor Bath
□ Basement
CO2 Concentration (ppm)
Time of Day (hour)

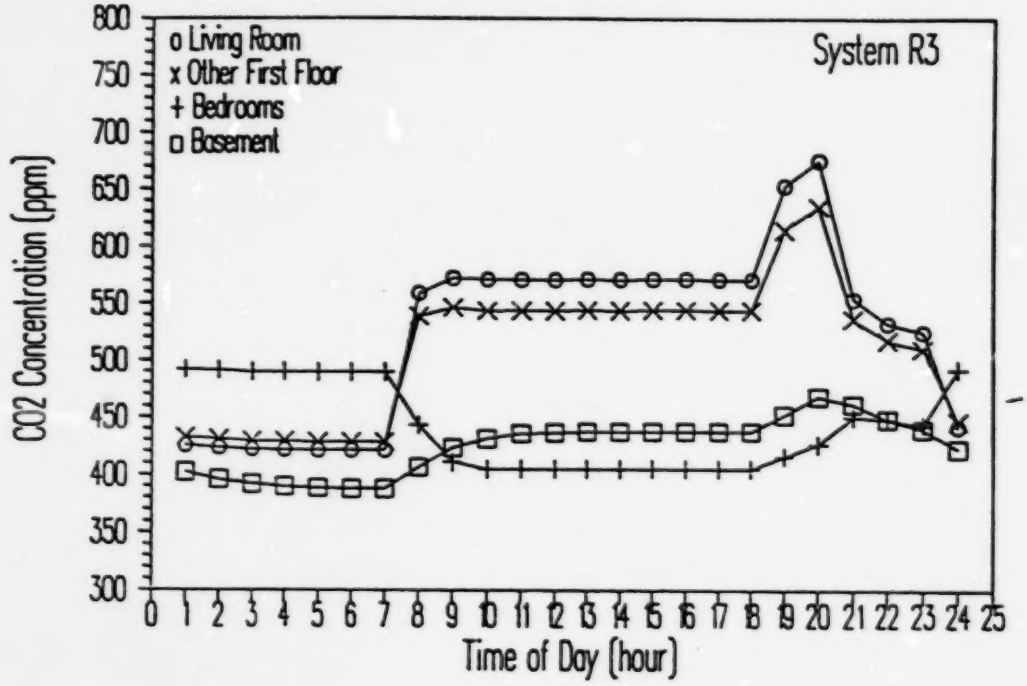

System NR2
o Living Room
x Other First Floor
+ Bedrooms
◊ Second Floor Bath
□ Basement
CO2 Concentration (ppm)
Time of Day (hour)

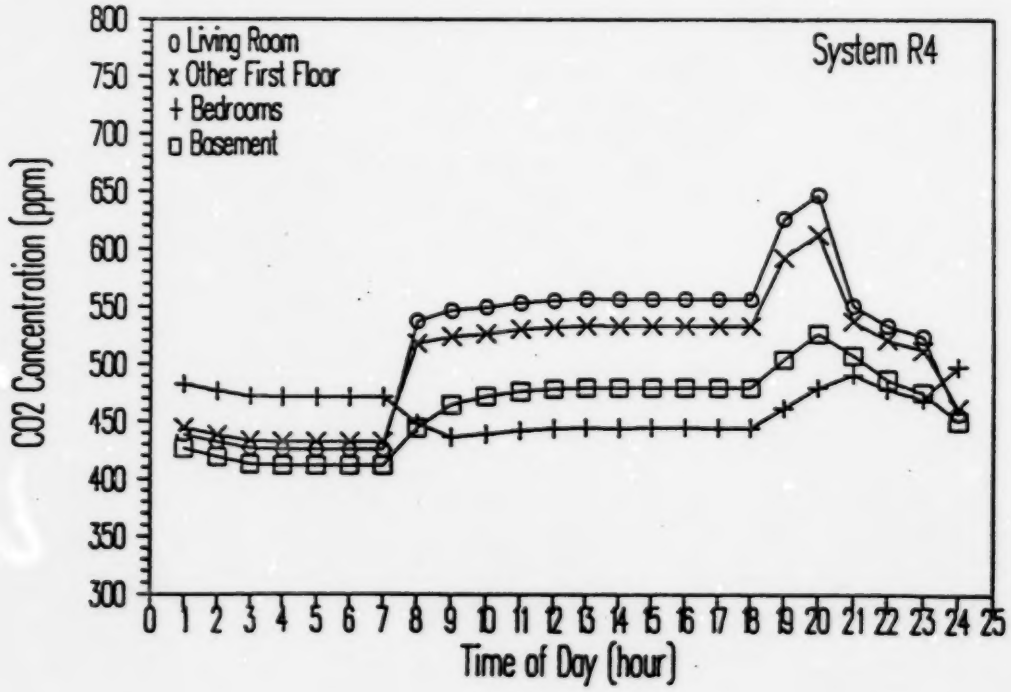

o Living Room
x Other First Floor
+ Bedrooms
◊ Second Floor Bath
□ Basement
System NR3
CO2 Concentration (ppm)
Time of Day (hour)

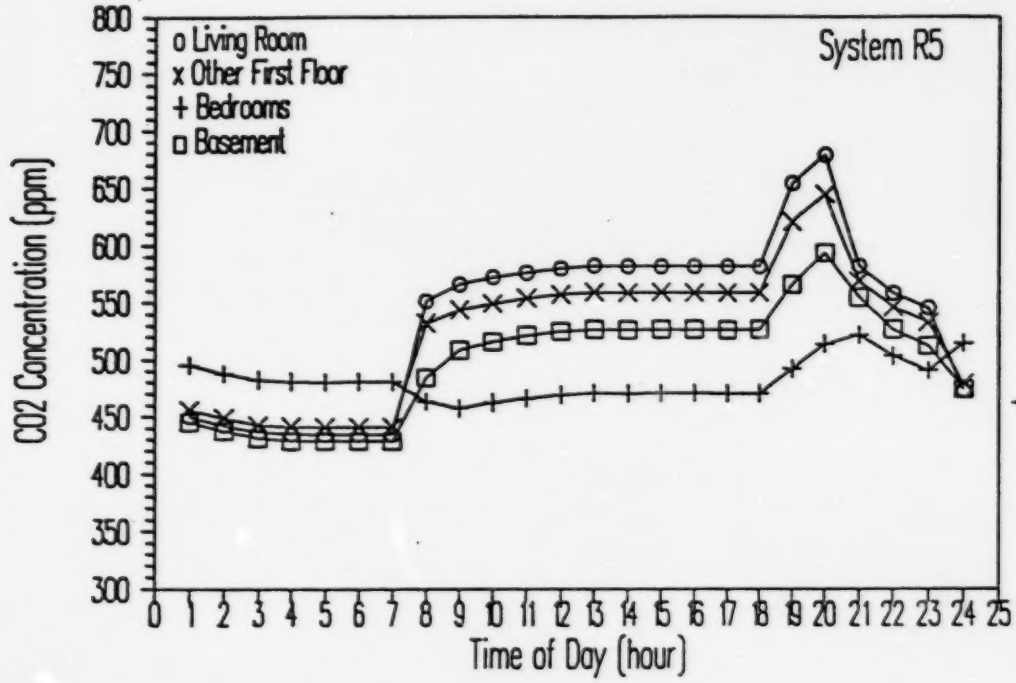

o Living Room
x Other First Floor
+ Bedrooms
◊ Second Floor Bath
□ Basement
System NR4
CO2 Concentration (ppm)
Time of Day (hour)

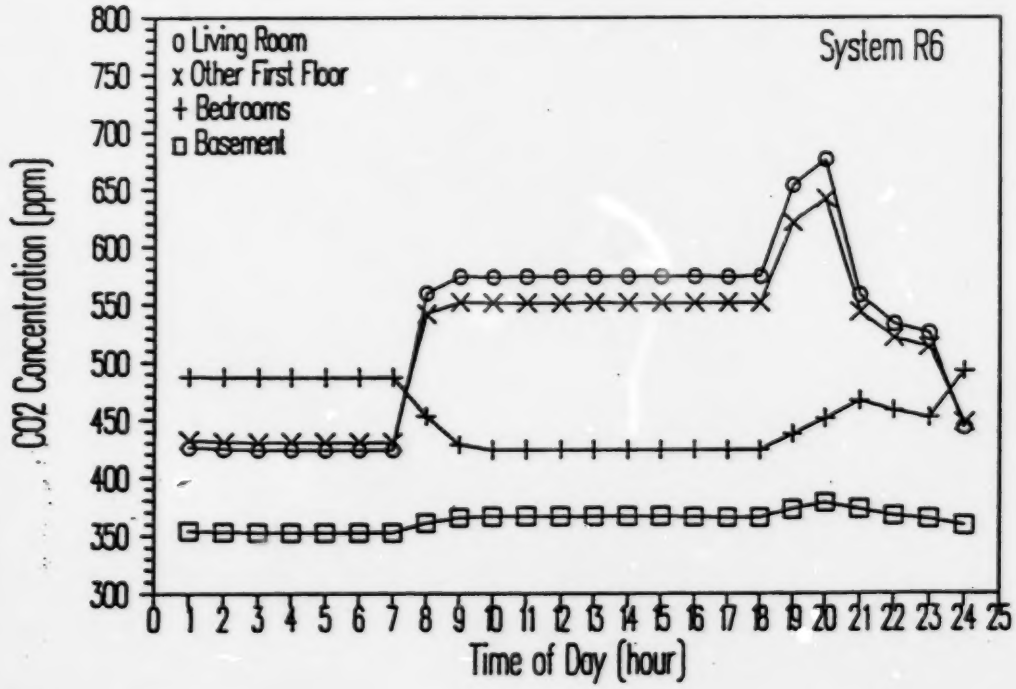

o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R1
CO2 Concentration (ppm)
800
750
700
650
600
550
500
450
400
350
300
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Time of Day (hour)


o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R2
CO2 Concentration (ppm)
800
750
700
650
600
550
500
450
400
350
300
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Time of Day (hour)


o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R3
CO2 Concentration (ppm)
Time of Day (hour)


o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R4
CO2 Concentration (ppm)
Time of Day (hour)


o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R5
CO2 Concentration (ppm)
Time of Day (hour)


o Living Room
x Other First Floor
+ Bedrooms
□ Basement
System R6
CO2 Concentration (ppm)
Time of Day (hour)